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Influence of martensite phase on the tribological properties of plain carbon steel

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Abstract

In the present paper wear behaviour of plain carbon steel having martensite phase under dry sliding condition has been investigated. Plain carbon steel material BS 970 / En 42 in the form of rods were selected to produce heat treated wear test pin specimens. Compositions, morphologies and microstructures of worn surfaces were characterized by scanning electron microscope (SEM), and energy dispersive spectroscopy analysis (EDS). Volumetric wear rate was investigated for these pins on pin on disc wear testing machine. Volumetric wear rate of martensite phase is more under low speed for all the normal pressure conditions. Wear behaviour was studied at different combinations of sliding speeds and the normal pressures with respect to the volumetric wear rate. Also the effect of parameters such as friction force and coefficient of friction on volumetric wear rate under the prevailing sliding speed and normal pressure condition was also studied.

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*Keywords:*Volumetric wear; Normal pressure; Sliding speed,; Martensite; Friction force, Friction coefficient.

1. Introduction

It has been difficult to model the processes involved in the regime labeled as plasticity dominated wear [S.C. Lim, et al.(1987)]. Several groups have shown that sliding creates a surface layer having near surface structure and properties different from that of the base material [P. Heilmann, etal. (1983)]. It has been demonstrated that smoothness of sliding and the type of wear debris depended on the relative hardness of the fine grain surface material and the adjacent base material [P. L. Hurricks, (1973)]. Wear resistance increases in the order of spheroidized carbide, martensite, bainite and lamellar pearlite even though hardness of lamellar pearlite is lower than that of martensite [M.C.M. Farias, et al. (2007)]. For hypoeutectoid steels bulk hardness of 350-450 VPN is necessary to support the generated oxide film and maintain a mild wear in air. Rubbing action also produces a surface hardness level of 350-425 VPN irrespective of the carbon content. From the present work it is observed that

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hard martensitic phase resists the wear at the initial stage. At higher normal pressures and sliding speeds due to frictional heating hardening takes place by structural strain transformations leading to mild wear. Effect of hardness disappears due to temperature rise and microstructural changes [Nam.P.Suh, et al. (1994)]. With further increase in the normal pressure, surface martensite loses its acicular structure and becomes lath type that reduces hardness to some extent and promotes the wear. Also it is observed that at higher normal pressures due to transformation of martensite ferrite and carbides precipitate. During longer sliding time carbide particles separate from the matrix of ferrite and get reduced in size. Further, these carbide particles spread onto the ferrite matrix and get embedded forming a hard, wear resistant surface layer. This layer resists the wear till it gets peeled off leading to increase in the volumetric wear rate [C.C. Vaifara, et al. (2009)]. With further increase in the normal pressure freshly formed asperities will break due to the build-up of contact stresses. Martensite being brittle its asperities are in pre-stressed condition. With increase in the normal pressure, frictional force increases due to increase in the intimate contact between the sliding surfaces. Whereas with increase in the sliding speed frictional force falls down because residential time reduces between the sliding surfaces.

2. Experimental details

For the tribological properties study, commercial grade steel was used as shown in Table 1. Wear characteristics of these samples were investigated after the heat treatment process. Samples of size 30mm lengths and 10mm diameter in the form of pins were used. These samples were covered with cast iron chips to avoid oxidation and subjected to heating above 840°C in a muffle furnace. After soaking for a period of 60 minutes, the samples were allowed to cool down in the furnace itself. Pins from sample were used for hardening process. These pin samples were heated again to 840°C, soaked for one hour for homogenization and quenched in water. This hardening process led to the formation of martensite.

2.1. Wear test

Wear tests were carried out with polished pins rounded at the edges. Both the surfaces of the pin were used for wear test at different sliding speeds and loads after cleaning with acetone. Dry sliding wear test was carried out using a hardened counter face of a polished disk of EN-32 with a hardness of HRC 62- 65 at a room temperature of 32°C. Pin on disc machine manufactured by DUCOM, Bangalore (India) was used. Weight losses of pin were recorded using an electronic balance having an accuracy of 10^{-7}Kg at different intervals of time. Tests were carried out at loads of 1, 3, 5 and 7Kg. and sliding speeds of 1, 3, 5 and 7m/s. Operating conditions were as shown in Table 2. After the wear test, worn out pin samples were coated with gold oxide to overcome the effect of oxidation and then studied under the Scanning Electron Microscope.

2.1. Preparation of test specimen

Before the wear test, samples were prepared by polishing, using polish papers of grade 4/0, 6/0 and then wet polishing was carried out using wet alumina paste of sub-micron grade. Specimens were etched with 2 % Nital solution and analysed under optical microscope. Micro hardness of the wear tested samples was measured using 0.005kg load on Vickers machine. Surface roughness of the worn out pin specimen was recorded using surface roughness tester of Mitutoyo Precision SJ-201.

Table 1 Composition of plain carbon steels

Composition	Grade	% C	% Si	% Mn	%P	%S
Sample	E.D.D IS 1079	0.87	0.251	0.342	0.007	0.005

Table 2 Operating conditions

Sl.No	Speed (m/s)	RPM	Time (min)	Normal pressure (MPa)	Sliding distance (meters)
1	1	212	167	0.1249	10,005
2	3	636	56	0.3747	10,065
3	5	1060	34	0.6245	10,185
4	7	1484	24	0.8743	10,065

3. Results and Discussions

3.1. Effect of normal pressure at constant sliding speed on volumetric wear rate and frictional force

From Fig. 1a it is observed that the trend for extremely low sliding speed of 1m/s and high sliding speed of 7 m/s is almost similar. Also the trend of medium sliding speeds of 3m/s and 5m/s is almost the same. The trend of extreme conditions and medium conditions are almost the reverse of each other. For extreme condition the volumetric wear rate decreases, increases and later again decreases with the increase in the normal pressure. Martensite is brittle with residual stress. This may be due to hard martensitic phase that resists the wear at the initial stage. As seen from the Fig. 1b with increases in the normal pressure frictional force increases due to increase in the intimate contact between the sliding surfaces, whereas with increase in the sliding speed frictional force falls down due to reduced residential time between the sliding surfaces.At low sliding speed of 1m/s, with increase in the normal pressure the asperities will not break easily, hence volumetric wear rate decreases as observed in Fig.2a. With increase in the normal pressure surface martensite loses its acicular structure and becomes lath type that reduces hardness to some extent and promotes the wear as seen from Fig.2b.With further increase in the normal pressure the asperities will break due to the build-up of contact stresses. Martensite being brittle its asperities are in pre-stressed condition. Therefore in the initial stage volumetric wear rate is high. With increase in the normal pressure fresh surfaces form, hence volumetric wear rate increases.Subsequent decrease in the volumetric wear rate is mainly due to the loss of number of asperities along with oxidation that get removed in the initial stages. Further this volumetric wear rate increases with the formation and peeling off of the oxidized surfaces which get exposed or form new surfaces, leading to further increase in the volumetric wear rate. Under high sliding speed, due to frictional temperature volumetric wear rate falls down because of the work hardening of the tempered martensite.

At very high normal pressures and/or speeds, frictional heating produces a more intensive form of hardening based on structural strain transformations bringing about a severe wear condition [P. L. Hurricks, (1973)]**.** Also increase in both normal wear pressure and sliding speed promotes a decrease in the tendency for martensitic transformation.[M.C.M. Farias, et al. (2007)].

3.2. Effect of normal pressure at constant sliding speed on coefficient of friction (μ)

As seen from Fig. 3 it is evident that the coefficient of friction decreases with increasing normal pressure for all the sliding speeds except for the sliding speed of 1m/s which is almost the same with increasing normal pressure. Under low normal pressure the coefficient of friction is high. Later with increasing normal pressure it is almost the same. Under low normal pressure the coefficient of friction is high because of the low intimate contactness, high surface roughness and low frictional temperature. With increasing normal pressure the coefficient of friction reduces due to low surface roughness and increase in the frictional temperature.

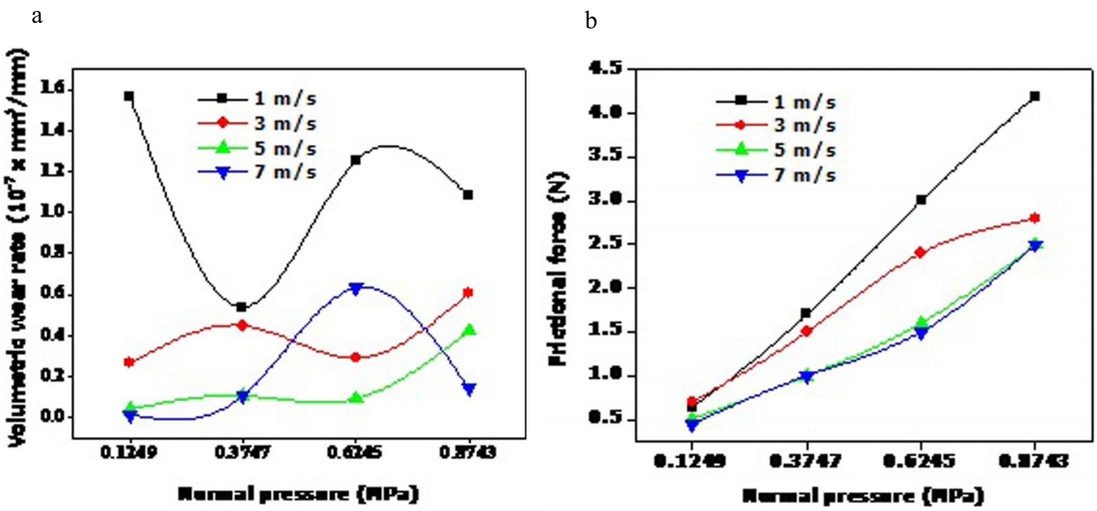

Fig.1 (a) Effect of normal wear pressure on the volumetric wear rate; (b) Effect of normal wear pressure on the frictional force.

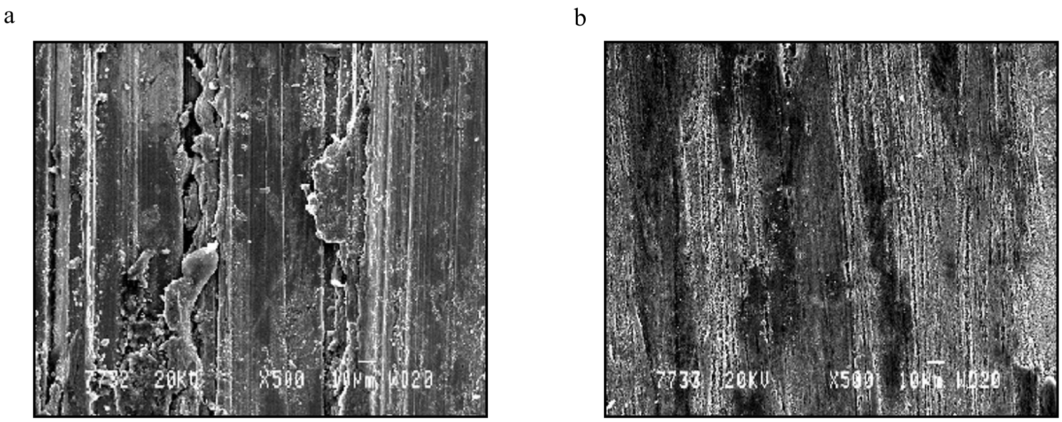

Fig.2 Shows SEM micrographs for (a) sliding speed 1m/s and load 0.1249MPa; (b) sliding speed 1m/s and load 0.8749MPa.

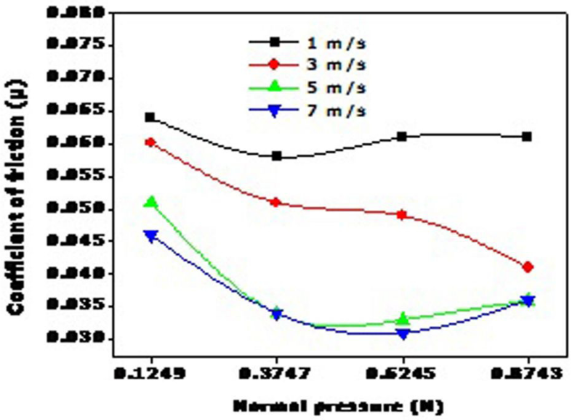

Fig.3 Effect of normal pressure on coefficient of friction at constant sliding speed.

3.3. Effect of sliding speed at constant normal pressure on volumetric wear rate and frictional force

Fig.4a shows that volumetric wear rate decreases with increasing sliding speed. This may be due to the frictional temperature, which causes the recrystallization of brittle work hardened layers and therefore inhibit severe surface spalling. At high at very high loads and or speeds frictional heating produces more intensive form of hardening based on structural strain transformations brining about a mild wear condition. The changes in mechanical and frictional properties of the surface layer produce due to heat evolution are difficult to control the process of wear [P. L. Hurricks, (1973)]. This decreases drastically to a very low value and continues to remain at that level with increase in the sliding speed, is due to the hard asperities of martensite that get removed easily in the initial stages. Later very few asperities are present that get locked easily in large numbers. Martensite being a hard phase offers wear resistance to further wear when the sliding speed increases. At this stage friction force increases slightly. This increase in the friction force causes frictional heating by structural transformations leading to mild wear reducing the volumetric wear rate. With further increase in the sliding speed, friction temperature increases, further softening the hard martensitic phase Fig.4b [P. L. Hurricks, (1973)].

a b

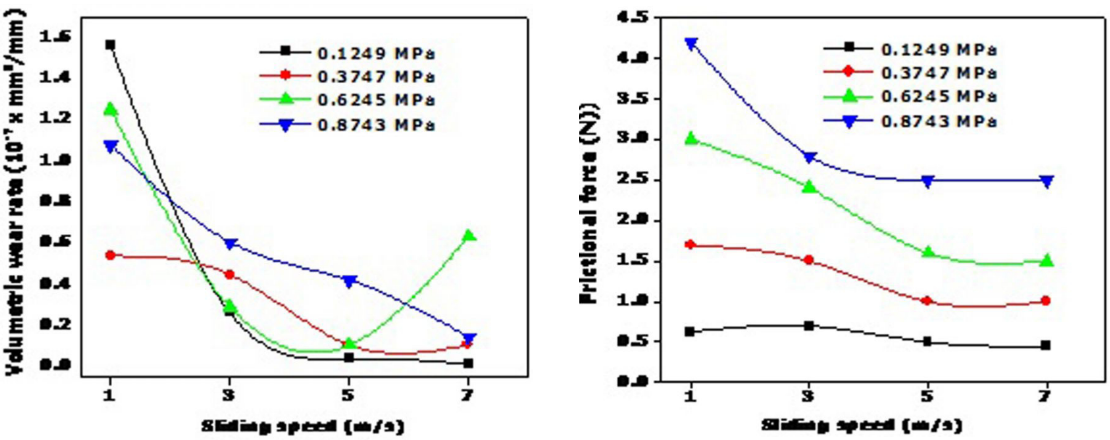

Fig. 4 (a) Effect of sliding speed on the volumetric wear rate; (b) Effect of sliding speed on the frictional force.

At still higher sliding speed the effect of high temperature leads to martensitic phase transformation into tempered structure forming ferrite and precipitating carbide particles. This resists the wear hence, the volumetric wear rate decreases slowly as seen from the Fig. 5a. As seen from the Fig.5b the values of friction force decrease with increasing sliding speed for all the normal pressures. With increasing sliding speed the frictional force decreases along with decrease in the residential time which results in the restriction on growth of the micro-welds. As the speed increases these asperities are broken and the surface roughness values are reduced. This reduces the friction force values also. With further increase in the sliding speed friction temperature softens the hard martensitic phase reducing the friction force. At higher sliding speed number of passes required to cause void nucleation decreases. This leads to reduced volumetric wear rate [C.C. Vaifara, et al. (2009)].

3.4. Effect of sliding speed at constant normal pressure on coefficient of friction (μ)

As seen from the Fig. 6 higher friction coefficient prevails at the low sliding speed condition. Increased wear rate is observed at these values of friction coefficients because thicker wear particles are formed and also faster rate of crack propagation takes place. This ultimately increases the volumetric wear rate. At higher speed due to more number of asperities in contact the inter-locking between the asperities reduces. Therefore the coefficient of friction is low. Also at higher speed frictional heating reduces the hardness of the hard martensitic structure.

a b

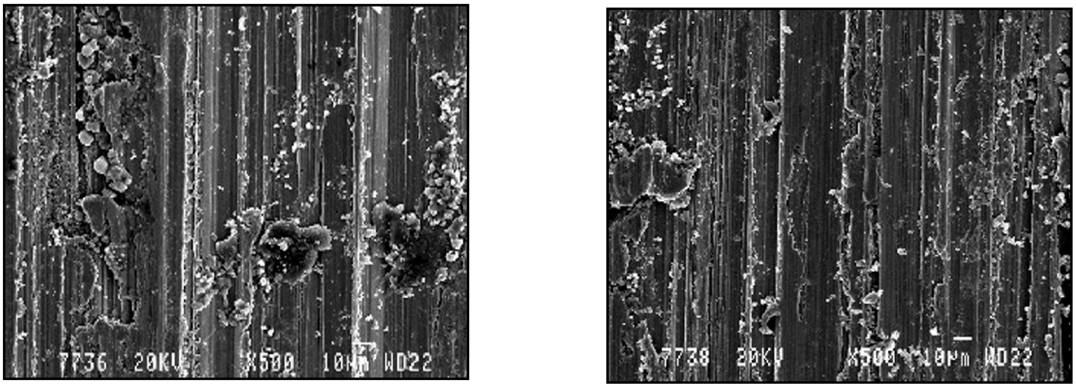

Fig 5 Shows micrographs for (a) sliding speed 1m/s and load 0.1249MPa; (b) sliding speed 7m/s and load 0.1249MPa

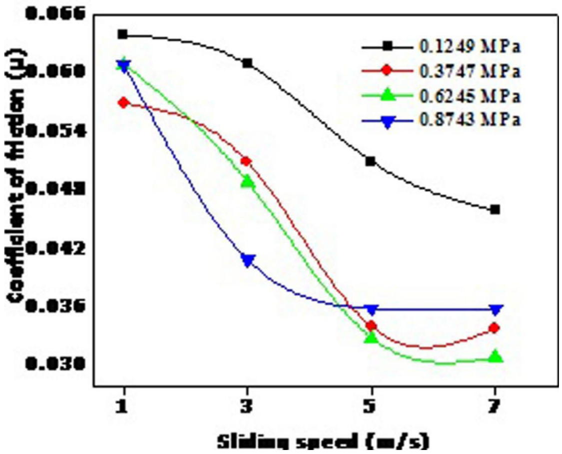

Fig. 6 Effect of sliding speed coefficient of friction at constant normal wear pressure.

3.5 Energy Dispersion Spectroscopy (EDS) Test.

Energy Dispersion Test carried out for the sample no.1 tested at a sliding speed of 212RPM and load of 0.1249 MPa.

a b

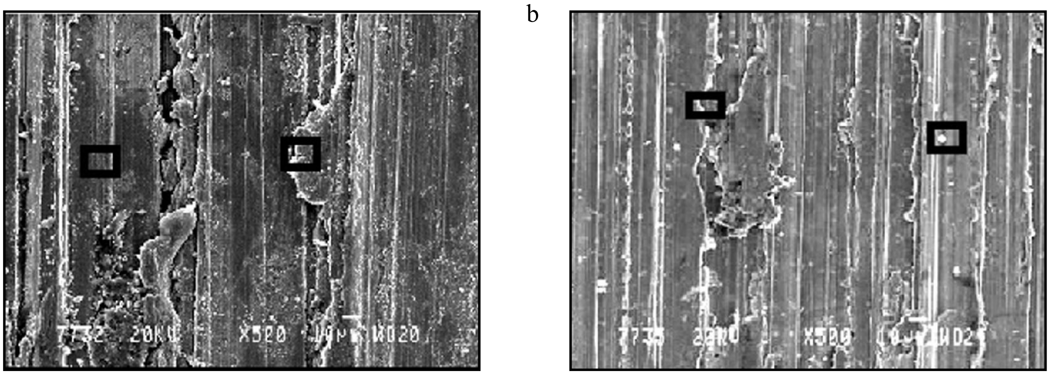

Fig. 7 SEM micrographs in EDS test for sliding speed and load (a) 1m/s, 0.1249MPa; (b) 7m/s, 0.8743MPa.

Table 3 EDS Result of sample no.1 for phase and chemical composition

Sl.No.	Location	Composition	Phase	O	Mn	Si	Fe
1	Point1	$Fe_{97}Mn_1Si_1O_1$	Martensite	0.28	0.86	0.48	98.38
2	Point2	$Fe_{98}Mn_1Si_1$	Martensite	0.32	1.23	0.38	98.08

a b

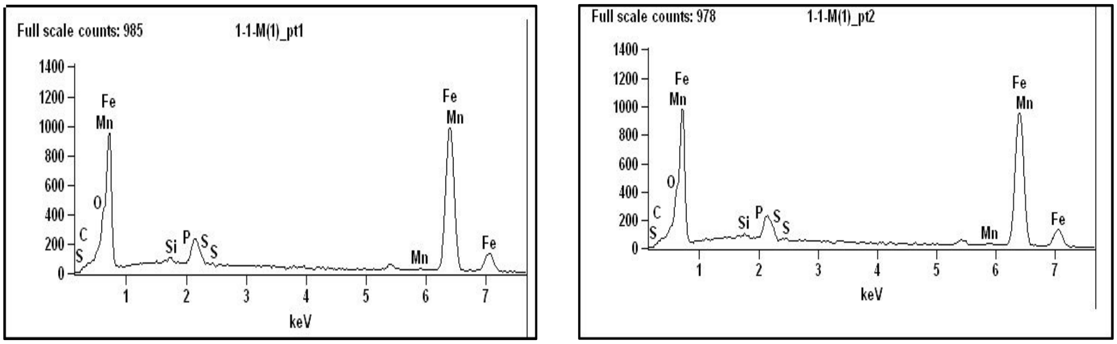

Fig.8 EDS Result for (a) Point 1; (b) Point 2.

It is observed that for sample no.1at lower normal pressure and lower sliding speed, oxides formation is almost negligible.

Energy Dispersion Test carried out for the sample no.2 tested at a sliding speed of 7 m/s and load of 0.8743 MPa.

Table 4 EDS Result for phase and chemical composition

Sl.No.	Location	Composition	Phase	O	Mn	Si	Fe
1	Point 1	$Fe_{80}Mn_1Si_1O_{18}$	Martensite	5.79	1.17	0.41	92.63
2	Point2	$Fe_{98}Mn_1Si_1$	Martensite	0.20	0.77	0.27	98.76

It is observed that for sample no.2 at high normal pressure and higher sliding speed**,** traces of oxides are formed.

a b

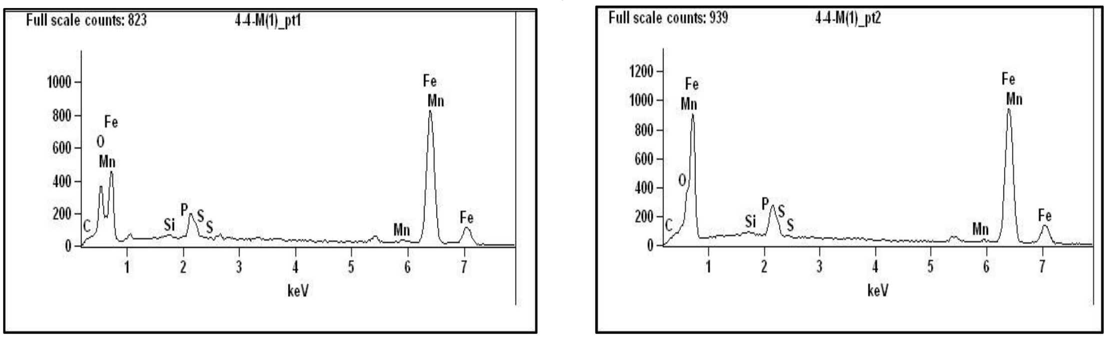

Fig.9 EDS Results for (a) Point 1; (b) Point 2.

4. Conclusions

- At the combination of higher normal pressures and sliding speeds, martensite wear is negligible.

- Volumetric wear rate for martensitic phase is observed only at the lower normal pressure for all the sliding speeds.

- Volumetric wear rate of martensite phase is more under low speed for all the normal pressures and almost negligible for higher sliding speed conditions.

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